Photometry of Bright Regions on Mars: ISM Results.
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Introduction. Compositional interpretations of reflection spectra depend on changes in spectral band positions, albedo, and continuum slope. Spectra of bright regions on Mars (0.77-3.14µm) show that surface effects cause the measured reflectance to decrease as incidence, emission or phase angle increases. Aerosols make the continuum slope more negative and shift band centers to a longer wavelength with increasing emission angle (Fig.1). To normalize the data to a common viewing geometry, first the reflectance is corrected for phase angle and opposition effects, then a Minnaert function corrects for varying incidence and emission angles, and finally the increase in reflectance with emission angle caused by aerosols is subtracted from the spectra. The result allows spectra measured at different viewing geometries to be more accurately compared.

Data used. The Phobos-2 ISM data used cover 0.77-3.14µm in 64 channels with a spatial resolution of ~25x25km^2 or 5x5km^2. The phase angles range from ~1-20 degrees, and the incidence and emission angles from ~1-65 degrees. Each of the 9 low resolution images has 24 scans by approximately 100 lines, and the two high resolution images have 8 scans by about 285 lines. Each line runs approximately west-east, and is taken at a constant phase angle. Thus each image has 24 or 8 scans each taken at a constant phase angle, but with varying incidence and emission angles.

Phase angle correction. The correction for varying phase angle (pha) uses an empirical relation consistent with Thorpe's opposition curve [1] from Viking red images. The first step in deriving this curve uses the Minnaert function to calculate for each pha the apparent reflectance R_o where $\mu=\mu_o=0$. To do this, for each scan covering smooth, bright areas, a Minnaert plot (Fig.2) is made using $y=\mathrm{Log}[R\times\mu]$ and $x=\mathrm{Log}[\mu\times\mu_o]$, where $\mu=\mathrm{Cos}$[incidence angle]; $\mu_o=\mathrm{Cos}$[emission angle]; and R=reflectance at 1µm. To ensure that only areas with similar photometric properties are included, areas that do not plot cleanly on the Minnaert plot are not used. This causes isolated bright or dark patches to be excluded. A line fit to the Minnaert plot gives $R_o=\mathrm{Exp}$[y-intercept] (Fig.2). This method is used for each scan that has sufficient homogenous, bright material to get a good result. These R_o values are plotted vs. phase angle, and to these data a fit of the form A + B×pha + C×Exp[-pha] is made (Fig.3). Dividing the reflectance by this curve corrects for phase angle effects, including the opposition surge, but does not corrected for varying μ_o or μ: R_p=(R×offset) / (A + B×pha + C×Exp[-pha])

=phase corrected reflectance

where R=ISM reflectance,

A=0.371; B=-0.00185; C=0.0725

offset=A + B×20deg + C×Exp[-20deg] to normalize the correction to pha=20deg

Incidence and emission angle correction. To correct for varying μ_o and μ, we use a Minnaert function with k chosen to correct for the effects of the surface alone, and thus it does not correct the effects of aerosols. Reflective aerosols increase the apparent reflectance of the surface with emission angle, which decreases the Minnaert slope (Fig.2), and thus decreases the Minnaert k value [2]. The k values have a minimum at short wavelengths, and converge toward k=0.87 at approximately 2.5µm (Fig.4). Therefore, we make a Minnaert correction using k=0.87:

$$R_{pm}=R_p\times\mu / (\mu_o\times\mu)^{0.87}$$

where R_{pm}=phase and Minnaert corrected reflectance.

Aerosol correction. Two of the images cover very homogeneous areas and also have a large range of emission angles (~5-60deg), which permits the effects of aerosols to be isolated. Within these two images, scans with the most homogenous mineralogy were chosen based on ratio plots of spectra across the image which have the least variation. For these scans, plots of R_{pm} vs. µ show a linear relationship (Fig. 5), so the slope of a line fit to this plot gives the increase in reflectance with emission angle due to aerosols, the aerosol slope $dR_{pm}/d\mu$. To remove the aerosol contribution for a given spectrum, the aerosol slope at each wavelength is scaled by the emission angle, and this is added to the spectrum:

$R_{pma}=R_{pm}$ + slope×µ, where R_{pma} = phase, Minnaert, and aerosol corrected reflectance.

The slope is generally negative, and the strength of the slope varies with location, but the correction to the entire data set uses the weaker slope to prevent introducing artifacts from overcorrecting.

Results. These photometric corrections bring the spectra into much better agreement within each image (Fig.6), and also improve the match of spectra taken from two different images which viewed the same location on Mars at different viewing angles. With these photometric corrections, it will be possible to derive firm conclusions about the mineralogy of the surface, regardless of viewing geometry.

References. [1] Thorpe, *Icarus 49*, 398, 1982. [2] Drossart et al., *Ann. Geophy. 9*, 754, 1991.

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Figure 1: Spectra of bright areas from Daedalia taken at varying ina and ema; pha=7 degrees.

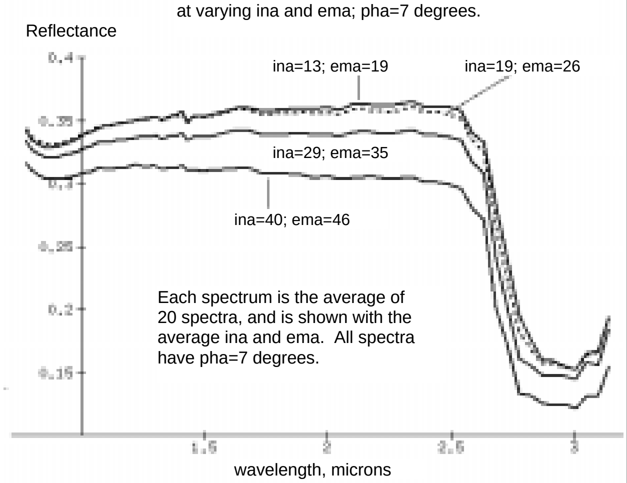


Figure 2: Minnaert plot showing the different Minnaert slopes at different wavelengths, and the Ro values calculated from the Minnaert plot at 1.07 and 2.5 µm.

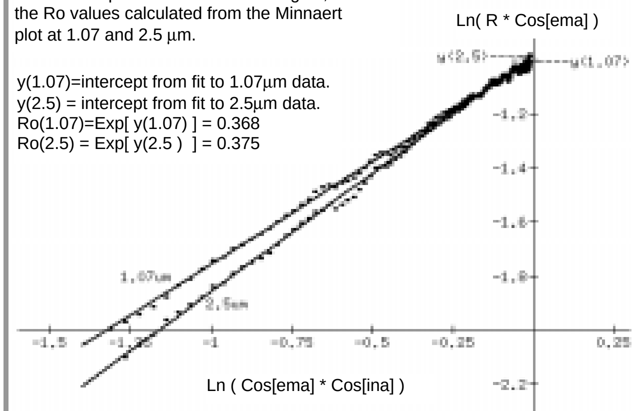


Figure 3: Phase angle correction:
The phase angle correction is made by dividing by the solid line shown. This corrects for the opposition surge at small pha and also for the gradual decrease in reflectance with increasing pha.

Fit made to homogeneous areas from 7 images. The dashed line shows the fit without the exponent term that corrects for the opposition surge.

Solid line = A + B*pha + C*Exp[-pha]
Dashed = A + B*pha

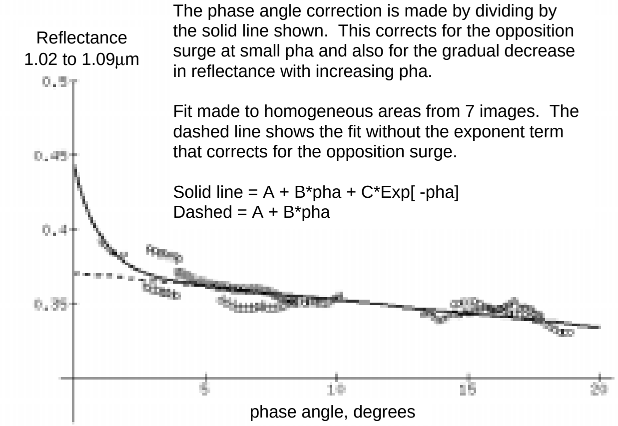
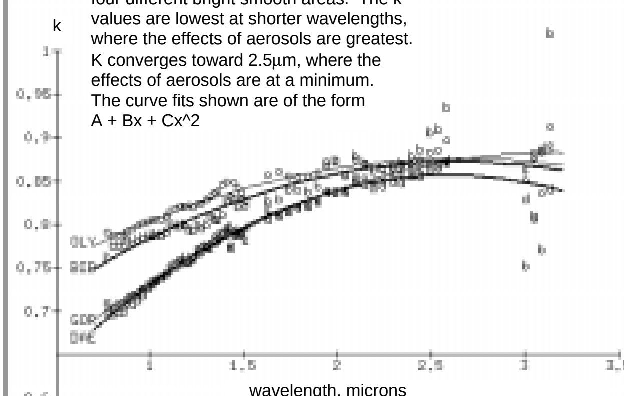


Figure 4: Minnaert k vs. wavelength from four different bright smooth areas. The k values are lowest at shorter wavelengths, where the effects of aerosols are greatest. K converges toward 2.5µm, where the effects of aerosols are at a minimum. The curve fits shown are of the form A + Bx + Cx^2



Channels 53-60 (2.63-2.96µm) dropped due to the strong CO2 band.

Figure 5: Aerosol slopes at different wavelengths: This shows the increasing reflectance with increasing emission angle caused by aerosols. Note the greater slope at shorter wavelengths.

This effect can be removed by using the emission angle of a given spectrum and the aerosol slope at each wavelength from this type of plot to find the magnitude of the aerosol contribution. The correction is then made by subtracting that contribution from the reflectance.

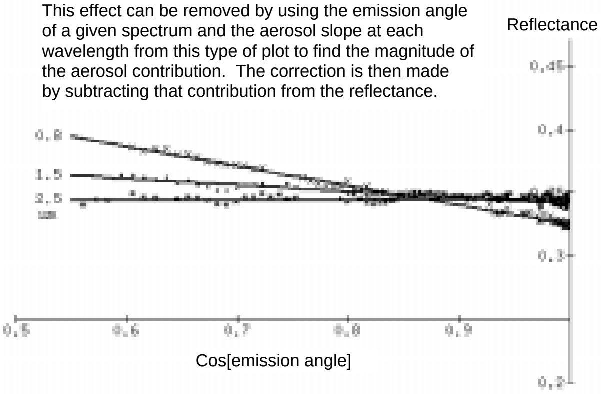


Figure 6: Same spectra as in Figure 1, except these have the phase, Minnaert, and aerosol corrections.